The Study on the Mechanical Properties of the De-Vulcanized Waste Rubber by a Mechanical Technique

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1. Introduction

Waste rubber recycling is a priority for waste management due to environmental impacts, resources saving, and raw material cost increasing. Presently in rubber industry, there is not real rubber recycling. In other words, recycled rubber can't be replaced with virgin rubber for manufacturing the new rubberish articles. To reach to the above mentioned goal, the chemical crosslinks in vulcanized rubber must be broken selectively, which improves mechanical properties of the recycled (de-vulcanized) rubber when again re-vulcanized. In this research, the recycling (de-vulcanization) of an ethylene-propylene-diene monomer rubber (EPDM) waste, obtained from automotive rubber parts was investigated. The de-vulcanization was performed by simultaneous using a semi-industrial twin screw extruder and a de-vulcanizing agent. A design experiment software was also used for deriving an equation for prediction of the de-vulcanization percent

2. Experimental

2.1. Waste rubber

The waste rubber powder was provided from PART LASTIC Company. It was a combination of waste new and second hand automotive rubberish articles. The TGA analysis (Table 1) was used to analyze the composition of the rubber waste. Before TGA analysis, the oil content of the rubber waste was extracted by Soxhlet extractor.

2.2. The compounds preparation and twin screw extruder de-vulcanization

The waste rubber powder and different amounts of the de-vulcanizing agent and oil were mixed in a simple mixer (Compounds 1-7, Table 2). After 24h relaxation, they were de-vulcanized in a semi industrial twin screw extruder (CTE65-52D, Coperion Keya Nanjing Machinery, Figure 1) with the outlet mass velocity of 40 Kg/h. Table 3 shows the crosslink densities (CLD's) and correspondent de-vulcanization percent for de-vulcanized compounds.

Table 1. The TGA and physical properties of the used waste rubber powder

Property		Amount
Sol content (%)		0.5
Density (gr/cm^3)		1.4072
Crosslink Density (mol/m^3)		186
TGA	Others (%)	15.45
	Carbon black (%)	43.60
	EPDM (%)	38.88
	Left oil	2.07

Fig. 1. The used twin screw extruder

3. Results and discussion

3.1. Waste rubber composition

Table 1 shows the TGA results for the acetone-extracted waste rubber powder. The EPDM degradation began at 287.6 °C and completed at 547.8 °C. Mass loss was also observed in the range 26.2–287.6 °C because of the presence of the oil. In addition to the mass loss related to the oil and rubber, a transition in the range 550–613 °C was observed. This was attributed to the combustion of carbon black present in the sample.

3. 2. Waste rubber de-vulcanization

The particle size of the waste powder was an important factor in controlling the de-vulcanization process. For large particles, i.e., 1 cm in diameter, controlling de-vulcanization process was practically impossible. However, waste rubber with a particle size of 1 mm was de-vulcanized efficiently. As observed in Tables 2 and 3, the presence of 6 phr TMTD (de-vulcanizing agent) caused 63.5 and 60.4% de-vulcanization for Compounds 1 and 2, respectively. The reducing of the main screw speed from 220 to 180rpm at the same temperature increased 3% de-vulcanization.

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3.3. Design of experiment and optimization of the results

For optimizing the main screw speed, an experiment design software (design-expert) was used. The de-vulcanization percent was selected as the response variable. For this purpose, response surface model (RSM) and a factor (main screw speed) was employed. The main screw speeds of 150 and 220 rpm were considered as lower and upper limits of the factor, respectively. The results of RSM showed that a second order model was suitable statistically. Hence following equation was proposed,

where N is main screw speed.

De-vulcanization% = -65.86570+ 1.32844N- $3.43251 \times 10^{-3} N^2$

3.4. Conclusion

In current industrial research, the automotive EPDM rubber waste was de-vulcanized with the aid of a mechanical method (twin screw extruder) and a chemical de-vulcanizing agent (TMTD), efficiently. The optimum condition for de-vulcanization was obtained for 180 rpm as extruder main screw speed at 220℃ .

Table 2. The prepared compounds formulations (all values in phr)

Compound no.	Waste rubber (phr)	TMTD (phr)	Aliphatic oil (phr)	Aromatic oil (phr)	De-vulcanization temperature (℃)	Main Screw seed (rpm)
1	100	6	10	10	220	180
2	100	6	10	10	220	220
3	100	6	10	10	220	150
4	100	6	10	10	220	160
5	100	6	10	10	220	170
6	100	6	10	10	220	200
7	100	6	10	10	220	190

Table 3. The CLD and de-vulcanized percent for de-vulcanized compounds

Compound no.	CLD $(mol/m^3$	Devulcanization %
1	67.9	63.5
2	73.7	60.4
3	82.5	56.4
4	80.6	58.5
5	73/0	60.0
6	68.3	62.0
7	68.0	62.4